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PROJECT [redacted]

Supplementary Report

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Approved [redacted]

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PROJECT REPORT

Supplement

I. Introduction

This report contains additional and supplemental material as requested by the D/I and 544th RTGp for Project The following topics are covered in this report:

The Control Extension Capabilities of the 544th RTGp

Communication between the Photo Producer and the Photo User

Calculation of the Printer Resolution for the SP/10/70 Printer and SO-278 Film

General Procedure for Testing Duplicating Equipment

Edge Acutance and the Effect of Edge Degradation on Mensuration

II. <u>The Control Extension Capabilities of the 544th RTGp</u>

During [redacted] investigation under Project [redacted] of the control extension capabilities of the 544th RTGp, an over-all flow diagram was developed. This diagram included the operations of the analysis center at SAC Headquarters, the operations at the Photo Records Services Division (PRSD), ACIC, and AMS. This diagram indicated a command function, a preliminary operational function, and a final operational function. Between the preliminary and final operational phases, there is a time delay while information is furnished to the 544th RTGp from PRSD and ACIC.

As a part of the total analysis of the capabilities of the research center, a detailed test program was conducted using simulated photographic inputs. These inputs utilized information which duplicated, as nearly as possible, the actual inputs to the research center. The results of this detailed investigation, as reported in the final Project [redacted] Report, proved a high degree of capability exists within the research center for performing the required tasks of target location by photogrammetric control extension means.

The major points which perhaps were not stressed sufficiently in the final report were the comparative capabilities and the time requirements for all phases of the target location program. In evaluating the capabilities of the research center, it is important to delineate those functions wherein complete control is maintained within the unit and those functions under which this unit has no command control. Such an analysis indicates that the present capabilities of the center are sufficient to perform the required task in this program. This sufficiency includes all relevant factors--such as equipment, personnel, training, space, time, and maintenance capability. The investigation pointed out the fact that the research center is not the gating factor in this program. That is, the services requested from PRSD and ACIC will control the quantity, and to a certain extent, the quality of work that this group is capable of performing. The selection of equipment, the training of the personnel, and the overall capabilities of the group show a high degree of proper planning in the building of such an effort.

This unit, as presently complemented, is entirely capable of keeping abreast of present methods and of investigating new methods to determine their suitability for use within this program.

III. Communication between the Photo Producer and the Photo User

Maximum intelligence yield from a given photographic product can be achieved only if the analyst or interpreter is given the best print or transparency for the particular job at hand. Depending on the requirements, the type of photo product best suited for his needs may vary widely. This is most true when the analyst is struggling with small, low-contrast detail, or when the detail in question is located at either extreme of the exposure range. Frequently, an additional print or set of prints made to meet a special requirement may provide substantial aid.

The initial transparencies or prints which the interpreter receives must be made to present the best average picture. Having located a specific problem area, the interpreter can then request special service from the Photo Lab. Here lies the pitfall. Unless the interpreter can state in language the photo technician understands, what his needs are, he may or may not receive the best product. Further, he may not know that it is not the best product, unless he has at least a basic understanding of photographic processes and materials, and is equipped to recognize defects in his prints. His ability to wrest information from the picture can be affected by a whole chain of events, starting with the planning of the mission, and carrying through the illumination and viewing system employed during his analysis.

In order to improve the special secondary prints, as well as securing new prints when defects are found in the originals, the interpreter must be able to recognize the defect, and to have a good idea of what he requires to get improvement. Two examples may point this out. A slight amount of slippage between original negative and duping film during the continuous printing operation may produce a narrow, blurred band across the print--just in a critical area. The analyst may accept this as a vagary of the system--and fail to secure the maximum information from that critical area. Or, if properly informed, he may immediately recognize the defect, know that a new print will cure it, and within an hour or so be working with a good print.

In another instance, critical information may lie in a bright, sunlit sandy area. The average print may fail to show detail in this area--not because it is missing in the original negative, but because the print exposure was too light, or the paper too high in contrast. The informed

interpreter will ask for a new print--made particularly to show the critical detail at its best. It may not be sufficient merely to ask for a darker print--best results will be mad if he actually indicates the particular detail that is of interest. Granted that it will take more time and care to prepare his request, but the results will in most cases more than justify it.

As an aid to the interpreter who must make his request through the medium of written orders, it is feasible to prepare special order forms, in which a number of pertinent facts or comments can be checked, and the location of the particular detail or region of interest noted. It will not be sufficient for the interpreter to request, "make a contrasty print of frame XYZ", or "a maximum enlargement of the airfield in frame XYZ". It is better that he specify a print "to yield best detail contrast in the forested area of frame XYZ", or "optimum enlargement to include the entire airfield and supporting areas", or still better, "optimum enlargement and print contrast to accomplish an aircraft identification and structure analysis".

The comments above apply also to the situation in which measurements are to be made of small detail. Since the accuracy of measurement is affected by the edge contrast, it follows that an improperly exposed print can introduce an error into the measuring process. This is particularly true on a paper print, because the dynamic (density) range of paper is appreciably lower than transparency material. For example, the maximum reflection density a glossy paper can reach, with very heavy exposure, is about 1.6; SO-278 duplicating film has a maximum density of about 2.4, and the faster G-2 duplicating film has a maximum density of over 3.0.

One course of action that could be taken to improve the ability of the interpreter to communicate his needs to the photo technician would be to prepare a manual for him which tabulates the defects he might encounter, and indicates the correction procedure, if any is possible. The manual should also include original photo prints which illustrate these defects, and the corrected appearance. The value of such a manual would suffer if illustrations are not original prints, since much of the significant detail would vanish in the half-tone screen reproduction.

Following is a table of common defects, separated into Pre-Printing, Printing (Contact Printers), and Printing (Enlarging Printers).problems, with suggested correction procedures.

A. Pre-Printing Defects

1. Underexposure	Print lacks contrast markedly in the shadow or dark areas. If taken under heavy haze, entire print may be very flat, still lackind shadow detail. Correction is difficult --dark and light print may help.
2. Image Motion	If due to excessive vehicle velocity for shutter speed used, blur will be parallel to flight direction. If due to vibration, blur will be random, having appearance of defocused image.
3. Image Defocused	Image (in original negatives as well as prints) will lack sharpness, especially when viewed under magnification. Cannot be corrected, except by sophisticated image enhancement techniques.
4. Overexposure	Negatives may be dense. Print may show excessive contrast; highlights blocked up. Correction is difficult--use lower contrast paper. In extreme case, chemical treatment of negatives may be helpful.
5. Overdevelopment	Negatives may be very dense. Prints may show poor contrast in dark areas, but excessive contrast in highlight areas. Correction idfficult. Make selective prints for dark and light areas.
6. Light Fogging	Prints may show light streaks, with loss in contrast in light areas. Definite pattern may or may not appear.
7. Static	Prints may show either very fine lightning--like patterns, or diffuse round areas. No correction except to minimize build-up in static charges in camera system, or when film is unwound, prior to processing.

8. Black Lines	If in print, probably due to scratched negatives. If parallel to flight direction, occured in camera or during processing. If random, occured from careless handling of negatives, or from rough handling of print prior to development.

B. Printing Defects (Contact Printers)

1. Incorrect Exposure (Refer to Figure 2)	Print may appear generally too light or too dark. Note, however, that in many cases, certain detail will be better rendered.
2. Incorrect Contrast (Refer to Figure 3)	Highlights washed out, shadow detail black. Remedied by change in paper grade, or use of lower contrast developer, or both. Again, contrasty prints may be best for certain detail.
3. Poor Contact (Refer to Figure 4)	Prints may show random areas of poor, unsharp image. Most likely at edges. Correction is to make new print, check equipment for tension or pressure.
4. Slippage (Refer to Figure 5)	If from continuous printer, print will show band of blurred image, the width dependent on the amount of slippage. Often may be so slight detection is difficult. Correction is to check equipment, make new print.
5. Printing through Base (Refer to Figure 6)	Image will be laterally reversed, and there will be loss in sharpness. Amount of degradation strongly dependent on type of printer. Correction is to make new print. Note: If original negative was exposed in system with odd number of mirrors, image will be laterally reversed in negative, and will appear correct when printed through base.

6.	Print or Transparency Background Grey	Print was fogged (exposed to unsafe room light, or too bright safelight), or material was improperly stored, or is too old. New Print required.
7.	Print Background Yellow	Print received insufficient fixing, or solution was exhausted, or received insufficient washing, or was dried at excessive temperature. Correction is to make new print.

C. Printing Defects (Enlarging Printers)

1.	Lack of Sharpness (over entire print)	Printer improperly focused. Can be separated from camera focus problem by checking if silver grain structure is sharp. If so, enlarger focus is OK, original negative defective. If grain appears blurred, new print called for. May also be due to vibration, particularly if magnification is great or negative dense, requiring long exposure time.
2.	Lack of Sharpness (localized)	May be due to non-flat negative, or damaged optical system, or non-flat paper or film in easel. Calls for new print, attention called to defect.
3.	Flat, Lacking in Detail Contrast	May be wrong paper or film grade, or may be due to dirty optical system. Calls for new print, attention called to optics.
4.	Print Shows Excessive Graininess	Magnification to high for negative. Excessive magnification can actually impair ability to see fine detail. Call for print at lower magnification.
5.	Detail Too Fine to be Seen Easily	Insufficient magnification used. Calls for print made at higher magnification--possibly photomicrograph under critical situation.

D. A Manual of Photographic Examples

Experience has shown that nothing is as effective in pointing out the deficiency in a photograph as showing the defective photograph itself. Constructive comments are equally well effected by a corrected print. The interpreter could profit from a manual which contains a series of original prints, each one illustrating one type of defect and showing a corrected print - if the defect is one that can be corrected in the duplicating process. This manual should contain original photo prints, not screened offset reproductions, since the printing process may well destroy the effectiveness of the presentation.

To illustrate what we propose, Figures 1 through 6 are included. Each figure demonstrates a particular error - some of them made in the original camera, such as image motion; others demonstrate the effect of paper contrast, or printing exposure, or printer failures, such as slippage.

The Special Projects Lab is in an excellent position to adapt this kind of presentation to the special requirements of the 544th TRGp, and certainly has the capability to prepare a very useful manual of this type. The examples shown here of course represent a small part of the total spectrum of reference material that could be prepared for the interpreter. With such a reference, the communication between the photo producer and the user should improve substantially. In many cases, the interpreter's order blank for additional photo aids could refer to specific examples in the manual.

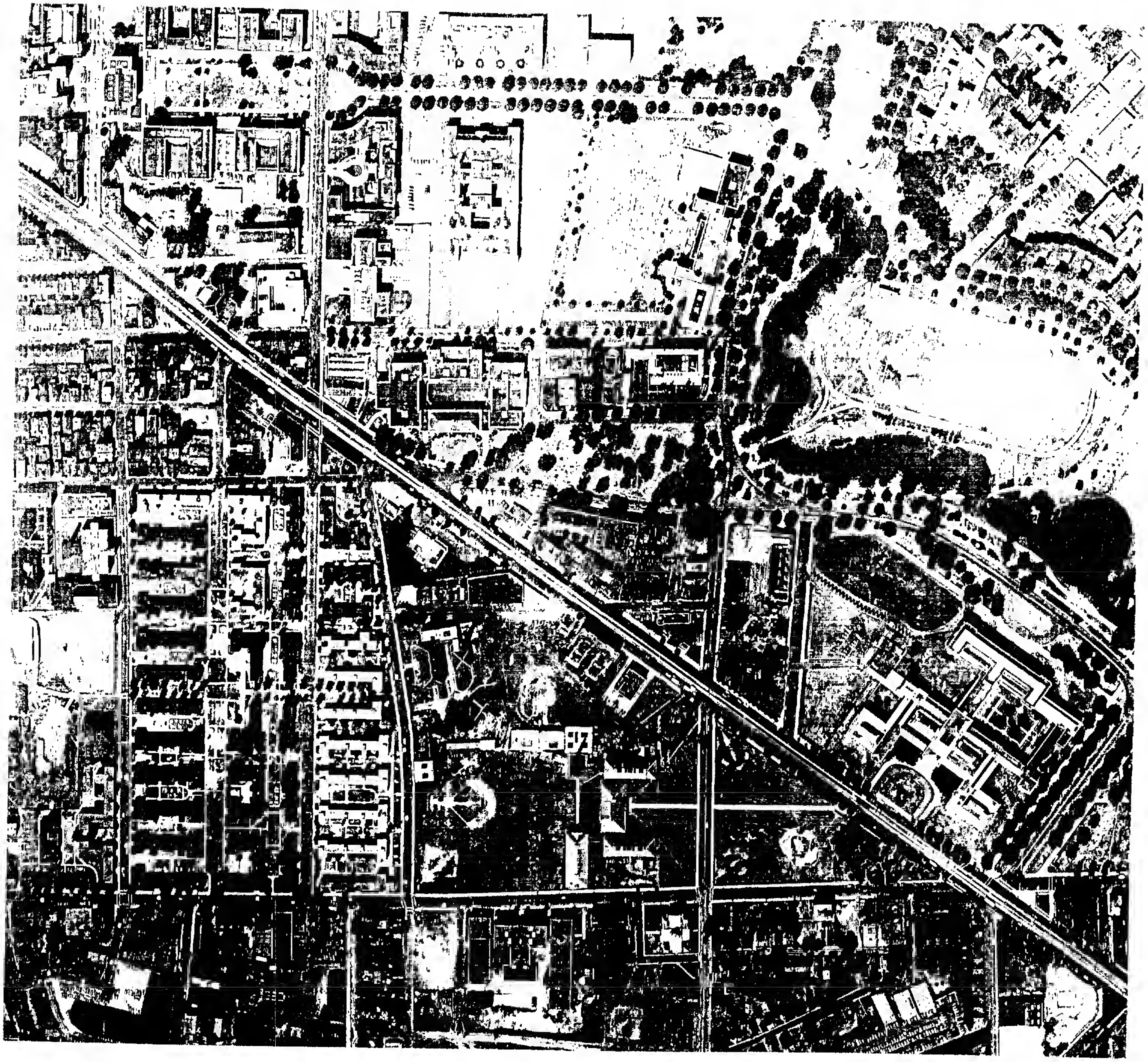
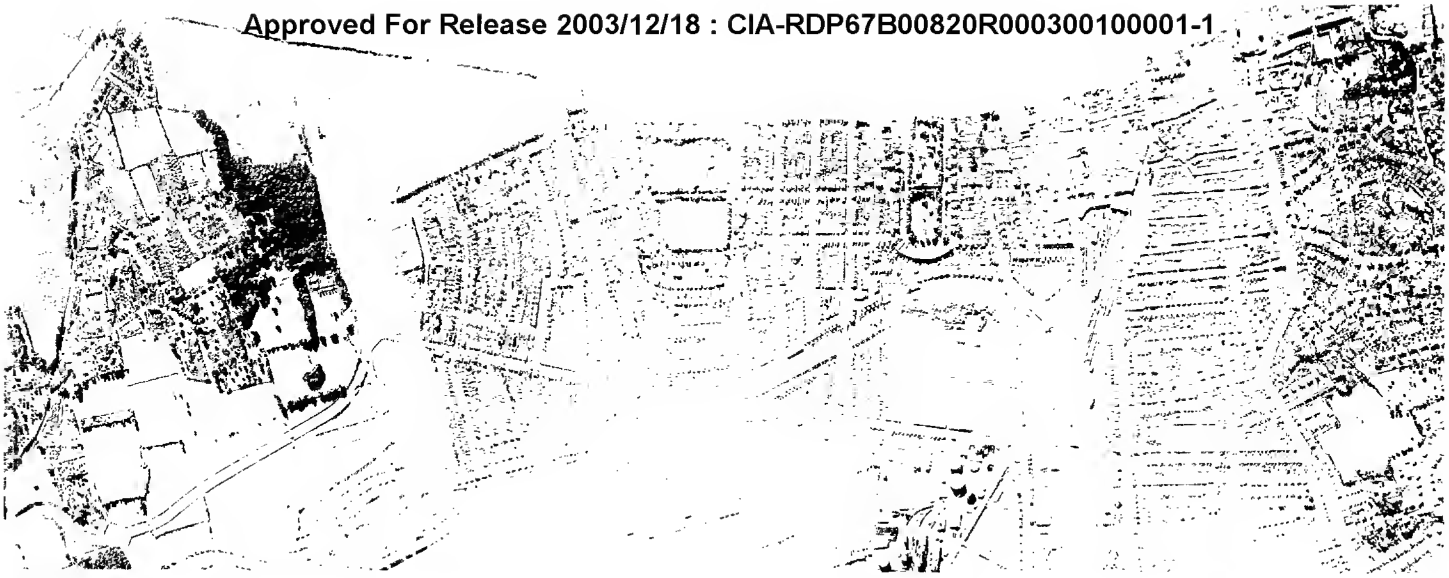


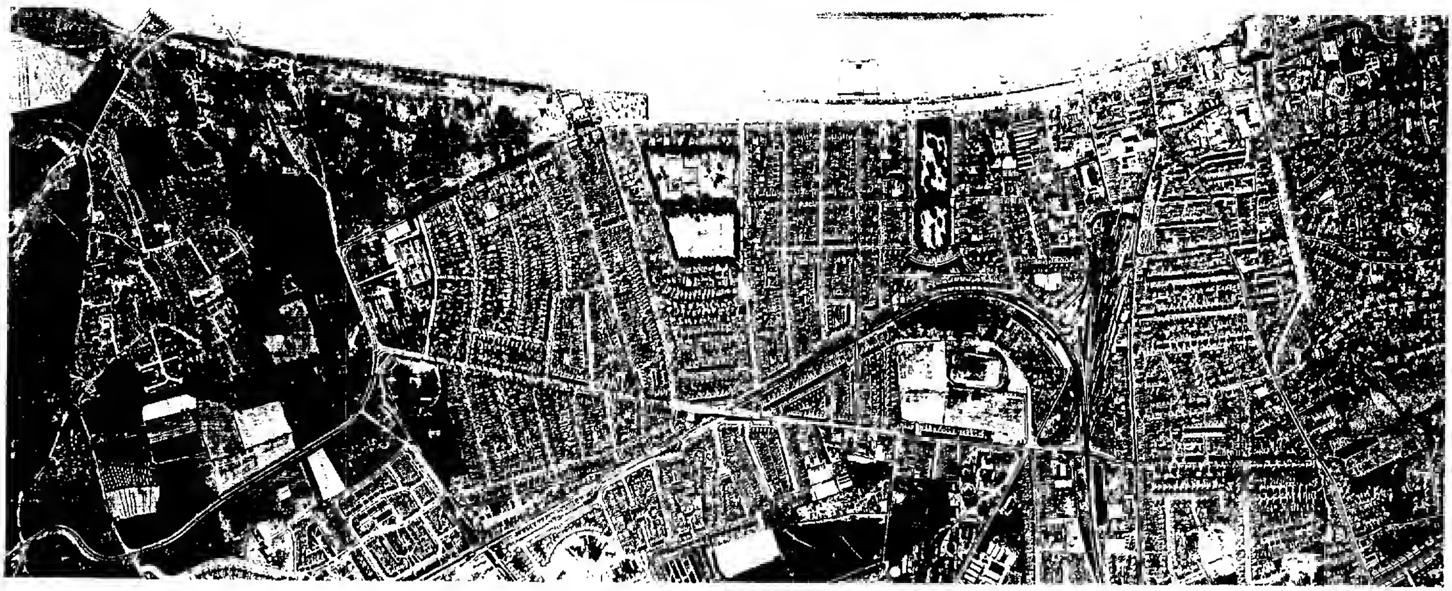
Figure 1

Image Motion

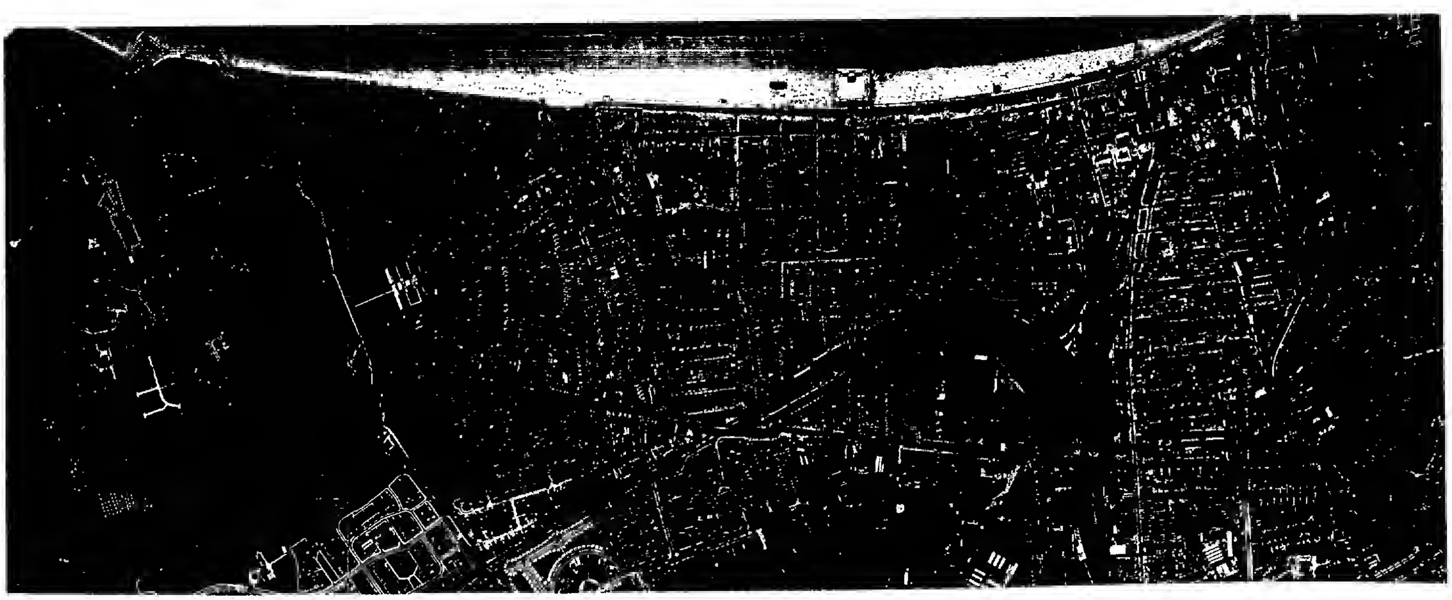
Requires Slight Magnification to be Readily Detected



Underexposed



Normal



Overexposed

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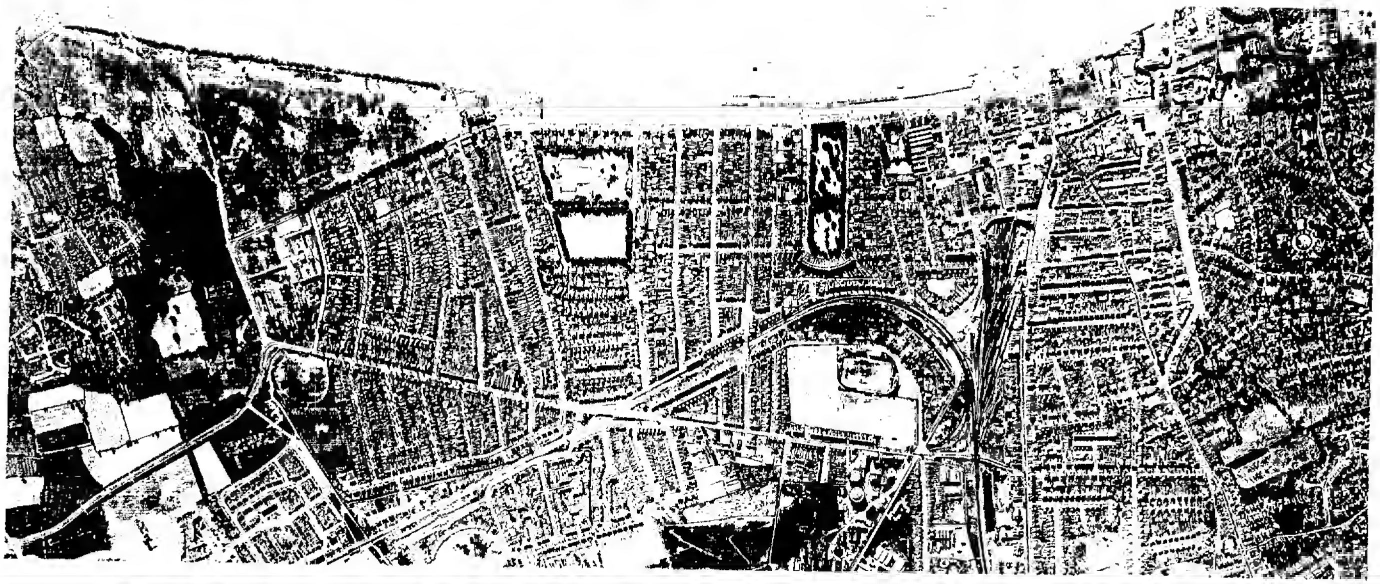
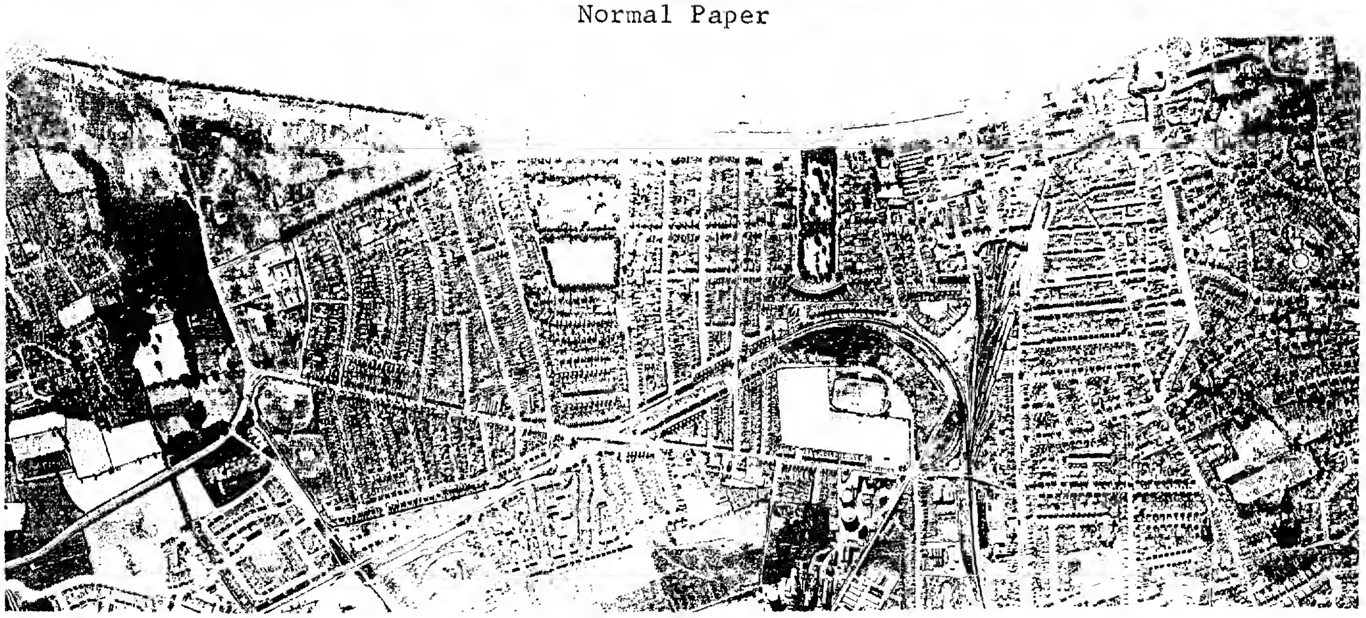
Figure 2. Effect of Varying Print Exposure Time

Note that all prints contain areas of optimum exposure for certain detail.

High-Contrast Paper

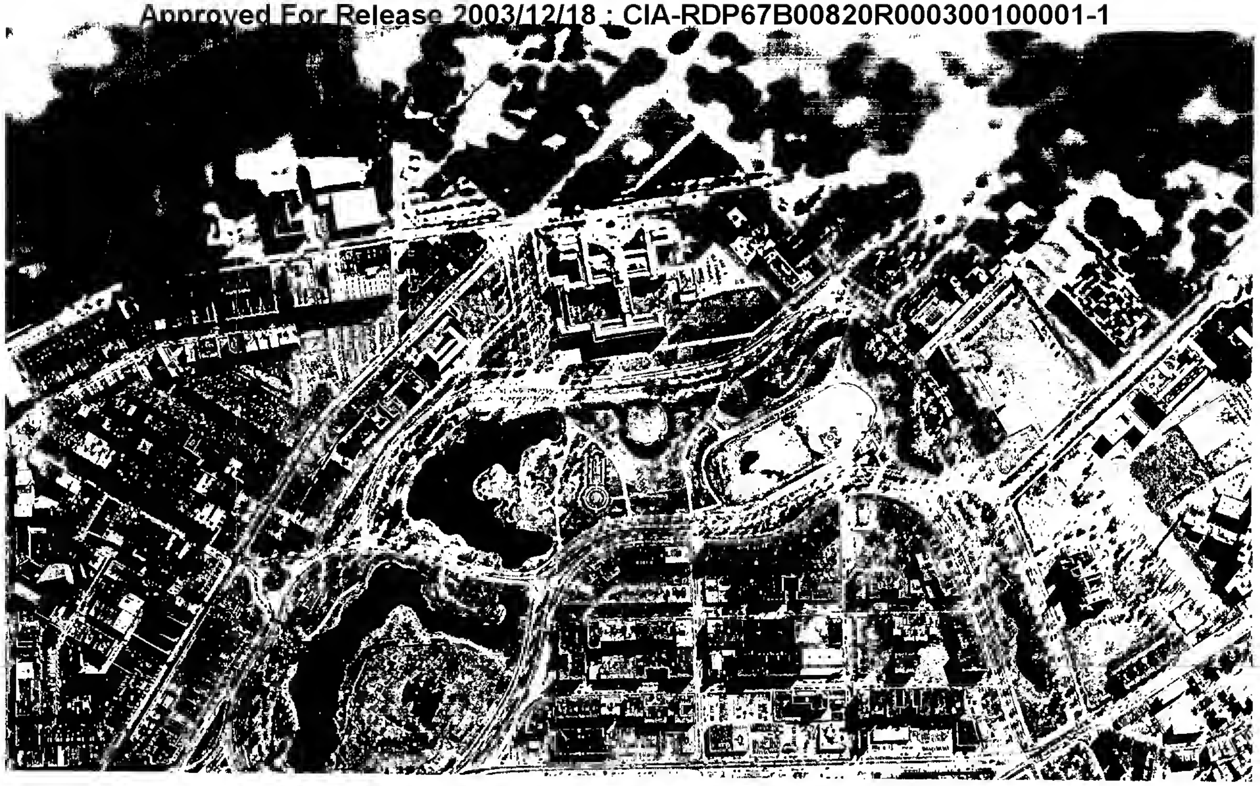


Normal Paper

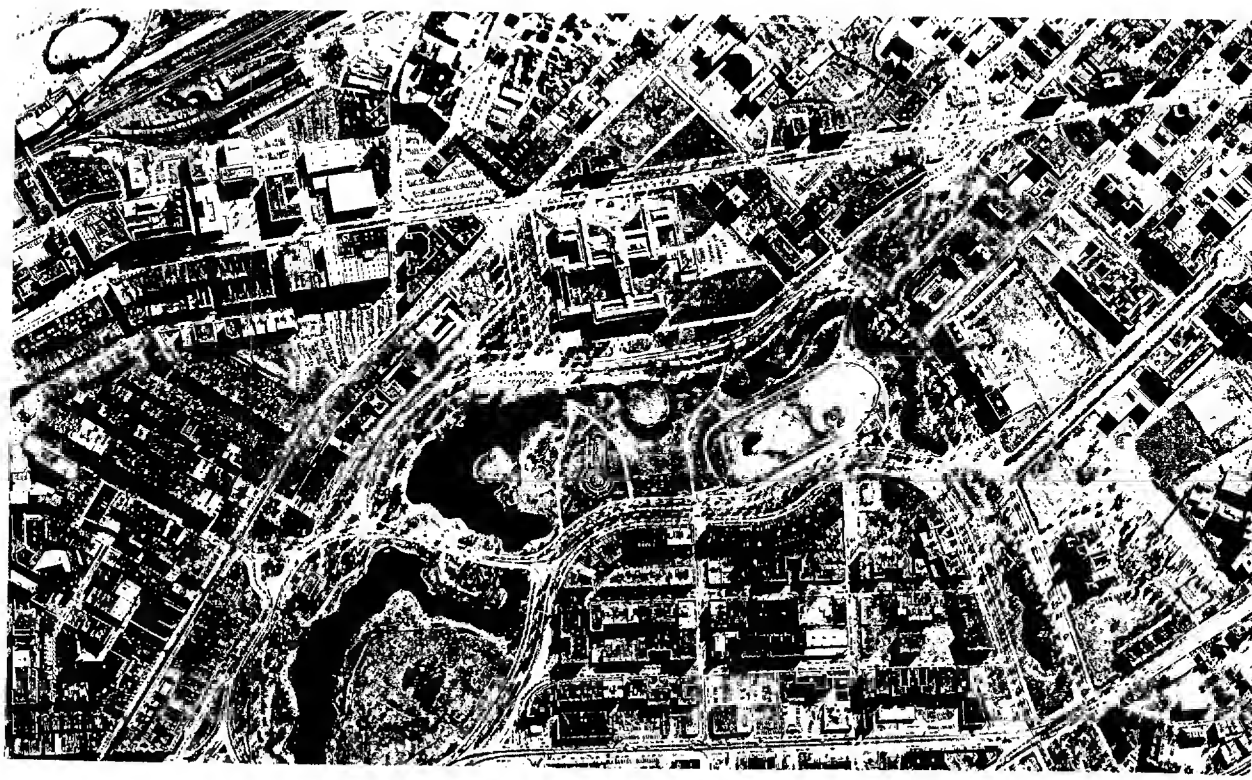


Very Low-Contrast Paper

Figure 3. Effect of Choice of Paper Contrast
Middle print best for most purposes



Poor Printer Contact



Correct Printer Contact

Figure 4. Effect of Failure to Maintain Good Contrast between Negative and Print during Exposure

Localized areas of image degradation due to mechanical slippage in continuous roll printer.

Gross Mechanical Slippage

FILM TRAVEL

Lesser Degree of Mechanical Slippage

Slippage Eliminated

Figure 5. The Effect of Gross and Slight Slippage between Original Negative and Duplicating Film (or screen) in Continuous Roll Film Printer.

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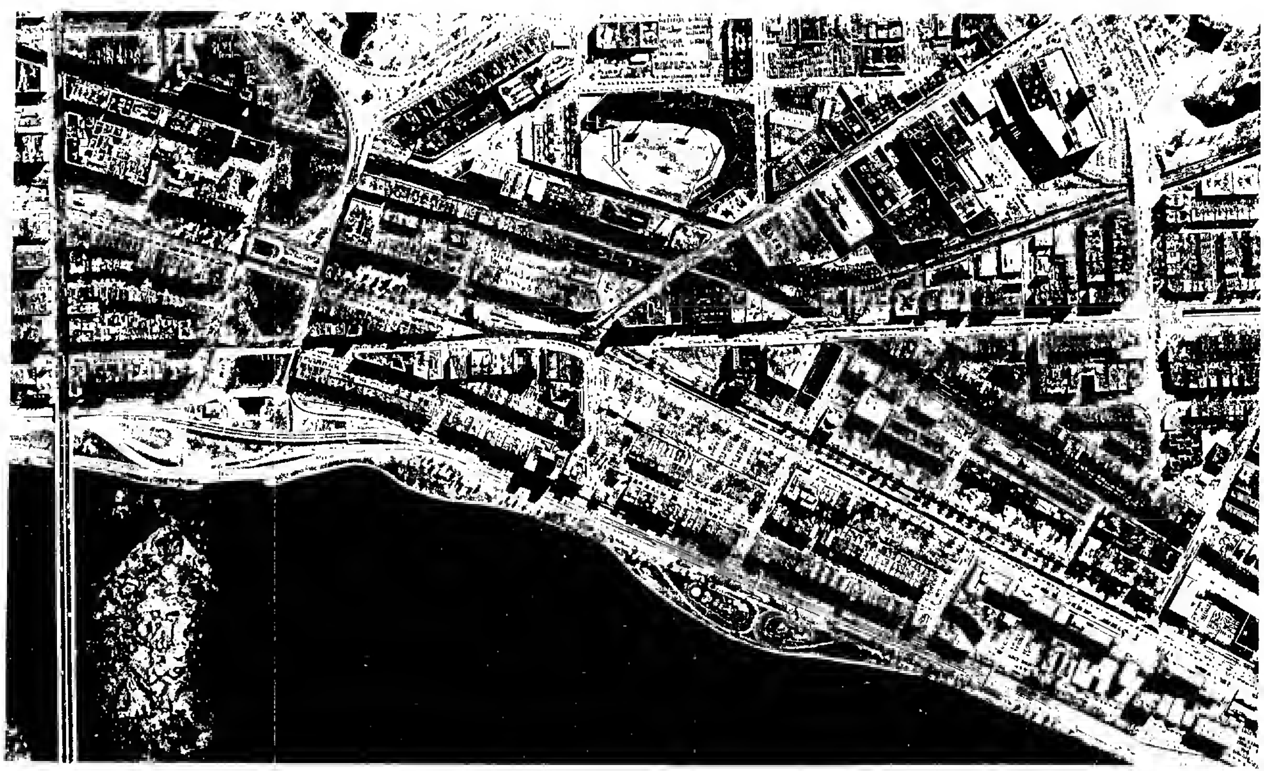
Image Laterally Reversed



Corrected Image

Figure 6. Effect of Printing through the Film Base

Note degradation of incorrectly oriented image (requires magnification).

IV. Calculation of Combined Resolution for SP 10/70 Printer and SO-278 Film

By making the assumption that the frequency response* of each component in a reproduction system is Gaussian in nature, it is possible to derive mathematically the following expression for the combined resolution of a duplicating system:

$$\frac{1}{R_c^2} = \frac{1}{R_i^2} + \frac{1}{R_p^2} + \frac{1}{R_f^2}$$

where R_c = combined resolution

R_i = resolution of original film image

R_p = resolution of printer

R_f = resolution of dupe film

If one can obtain values of R_c experimentally, as for example by the procedure for printer testing outlined in another section of this report, and if the individual values of R_f, R_i are known, then the value of R_p can be calculated.

STATINTL In the [redacted] study, values of R_c were obtained on several printers, through several generations. In these tests, however, the value of R_i was deliberately made low, by preparing a specially degraded resolving power target. Two test films were used--one with a limiting resolution of 48 l/mm, and one with a limit of 38 l/mm. The purpose of these tests was <u>not</u> to obtain data from which to calculate numerically the "printer resolution", but to determine the effect of the printer on test films which contained degraded targets simulating the limit of typical reconnaissance photography at the time of the investigation. As the [redacted] Final Report showed, all the printers tested produced STATINTL notable losses in resolution from these special test films.

In order to determine the combined resolution for the SP 10/70 printer with SO-278 film, the most accurate way would be to follow the procedure described elsewhere in this report, using a high-quality, non-degraded resolution test target with a resolution range which extends beyond the capability of the duplicating film.

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*Frequency response, also known as sine-wave response, is a measure of the ability of the lens, film, or printer, to reproduce the contrast in the original image as the detail size <u>decreases</u>, or the frequency <u>increases</u>. It is frequently expressed by plotting contrast (response) versus frequency.

An alternate approach is to use the data obtained with the degraded target, and to solve the equation shown earlier for R_p. Referring to the test data for the SP 10/70 printer, we find that the combined average resolution in the first-generation printing was about 39 1/mm. Using this value for R_c, and 100 1/mm for R_f (Type G-2 duplicating film), and 48 1/mm for R_i (the limit of the degraded test target), and substituting in the reciprocal squared equation, one can calculate that the printer resolution R_p is 90 1/mm. Having found this, and taking the high-contrast resolution for SO-278 film as 335 1/mm, the same expression can be used again to find a new film/printer combined resolution. This value is calculated as follows:

$$\frac{1}{R_c^2} = \frac{1}{R_p^2} + \frac{1}{R_f^2}$$

$$= \frac{1}{90^2} + \frac{1}{335^2}$$

$$R_c = 87 \ 1/\text{mm}$$

In the following graph, the combined printer/film resolution is plotted against printer resolution, for SO-278 and for G-2 film. This data shows the combined printer/SO-278 resolution to be 87 1/mm, and the combined printer/G-2 resolution to be 76 1/mm. This latter value does not, and should not, agree with the experimental combined average resolution of 39 1/mm mentioned above, because the experimental value was determined from a degraded test target rather than a high-quality test target. From the graph, note that the film choice becomes important for printer resolutions higher than about 80 1/mm.

A useful set of values to bear in mind are the following: When one component of a system is three times better than the other, the degradation caused by it will by 5 per cent or less. This is so small that it is difficult to verify it experimentally. Remember that these numbers are based on the reciprocal squared relationship, which is valid if one assumes that the frequency response curves have a Gaussian shape.

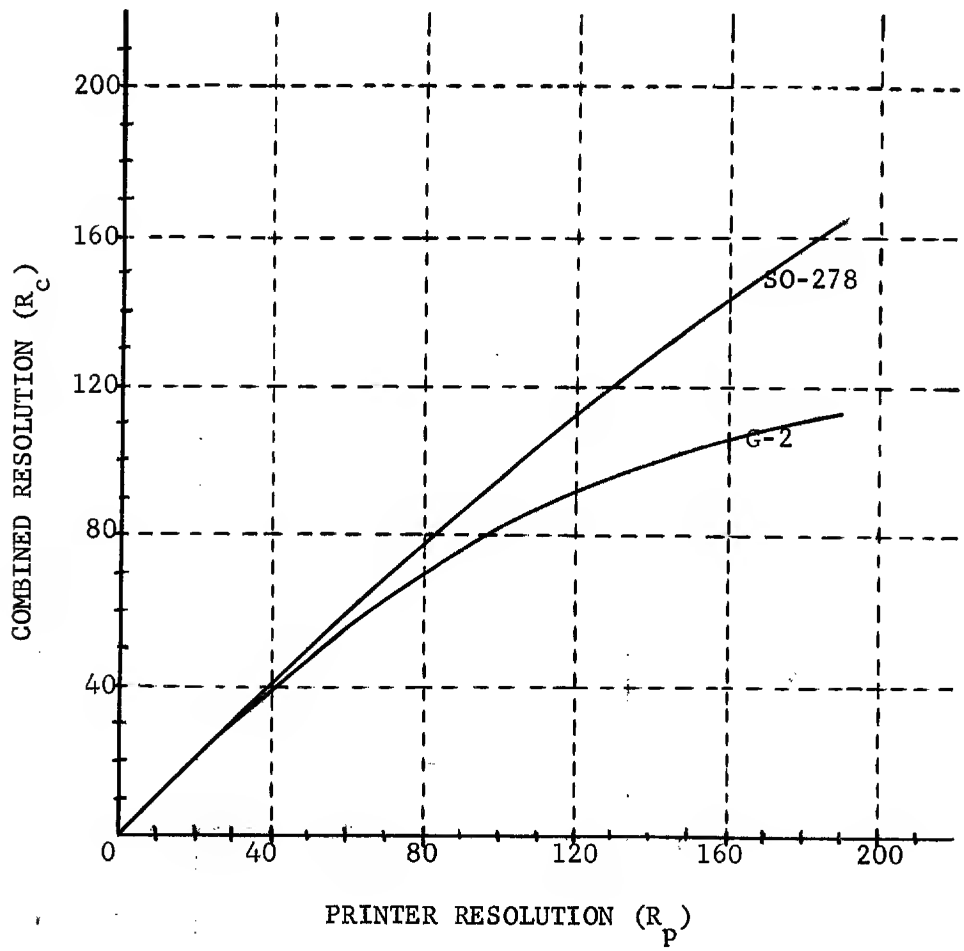

Figure 7

Combined Printer-Film Resolution as a Function of Printer Resolution for Two Duplicating Films, SO-278 and Military Type G-2, based on the Reciprocal Squared Relationship

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V. A General Procedure for Testing Duplicating Equipment

The procedure described below is intended primarily for testing of continuous roll film printers. Modifications of the procedure for testing step-and-repeat printers, or hand-operated, single-frame printers, or enlarging printers will suggest themselves.

The procedure can be readily carried out by the photo lab personnel who operate the 544th RTGp Special Projects Lab. The test will determine the ability of the printer to reproduce a resolving power target pattern over the full film width.

A. The Test Film

The test film shall consist of a length of the appropriate width high-resolution film, consisting of a minimum of six feet of leader and trailer with an array of high-contrast resolving power targets in the center, dispersed over a typical frame area. (For example, 9 by 18 inches, or 9-1/2 inch film, or 2-1/4 by 2-1/4 inches on 70 mm film.) The target array should contain at least 13 targets, arranged according to MIL STD-150A, with one major exception. Since the MIL STD-150A layout is intended for lens testing, the off-axis patterns are rotated so that the lines are radial and tangential with respect to the axis. For printer testing, the targets should be arranged so that the groupe of lines are parallel and perpendicular to the direction of film travel. This will simplify the analysis. The test film must be made on Eastman Kodak High-Definition Duplicating Film (SO-105), or Eastman Kodak 649 Spectroscopic Film, or an equivalent film having a resolving power capability of at least 1,000 l/mm.

B. Test Procedure

1. The test film should be spliced with additional leader, and threaded through the printer so that when the target area reaches the printing area, the instrument will be running under normal conditions.

2. The unexposed film type should be similar to that normally used for duplication, if representative resolution values for normal operation are desired. If maximum printer and film performance are sought, then special slow duplicating films such as Eastman Kodak SO-278 or SO-105 should be used--provided the printer has sufficient printing intensity.

3. A series of test exposures should be made first, with exposure increasing in square-root-of-two (about 40 per cent) steps. This can be accomplished by changing light intensity or by changing film transport speed.

4. This test run should be processed to a gamma between 1.0 and 1.2, using standard developer and equipment. The film should not be overdeveloped. Temperature should be 68° F ± 1/2° F. Drying should not be forced.

5. Microscopic examination of the exposure series will be required to select the best exposure, or to determine if an in-between setting is indicated. This examination should be conducted with a monocular or binocular microscope, having magnification of at least 50X, and preferably up to 100X. (The proposed ASA Standard calls for magnification ranging from .3 to 1.0 times the maximum resolving power of the system.)

6. After setting the printer for the best exposure level, a new test film should be exposed and processed as above.

7. The analysis of the test film should be conducted by at least two, and preferably three, observers, who examine each of the thirteen targets under the microscope and record the last resolved group in both the parallel and perpendicular directions.* Note that lines parallel to the film travel direction will measure the resolving power across the film width, while lines perpendicular to the film travel direction measure the resolution in the travel direction.

When the thirteen individual targets have been read, an average resolution for the two directions can be computed. Maximum and minimum readings should be noted, and any special degradation, such as the presence of slippage or poor contact should be indicated.

The above test can be repeated with a test film containing low-contrast test targets. The MIL STD-150A and the proposed ASA standard agree on the following values for high, medium, and low contrast:

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*The decision about whether a given set of three lines is resolved or not requires care. The criterion most workers use is that a density difference must be seen between each pair of the three lines along the <u>entire length</u>. Exception may be made if a scratch or dirt has obviously impaired the reading, or if there are two or more smaller groups that are resolved beyond the one in question.

Contrast Description	Density Difference	Luminance Ratio
High	2.0	100:1
Medium	.8 ± .05	6.3:1
Low	.2 ± .02	1.6:1

Note that if several values of performance are obtained at different contrasts, it is possible to calculate the frequency response of the printer. An alternate method for this would, of course, be to use a special test film with microscopic sine wave test targets; however, the analysis of these images requires a microdensitometer and a fairly extensive mathematical analysis. At the present time, as far as this author knows, no technique has been devised for making faithful sine wave test targets on a production basis. We suggest that the USAF might profitably support research in techniques for making such test patterns.

VI. Acutance and the Effect of Edge Degradation on Measurement

An aerial photograph presents to the observer a pattern of random densities and edges. In some instances, particularly with cultural detail in the scene, much information may depend upon the sharpness of the photographic edge, which is the boundary between contiguous regions of differing densities. Although the sharpness of the negative is a subjective evaluation, it can be correlated with an objective quantity which is determined from the photographic edge. This quantitative concept is termed acutance, and is measured for a specific emulsion under given conditions of illumination and development in the following manner.

Collimated light is used to expose a knife edge in close contact with the emulsion under test, such that there exists a (perfectly) sharp line of demarcation between the parallel rays of light incident on the surface of the emulsion and the region of non-illumination blocked by the knife edge. Diffusion of the light in the emulsion itself and adjacency effects in the development process, however, render a smooth rather than a sharp transition in density of the developed image, as shown in Figure 1.

It is apparent that two factors are required to describe this smoothened edge. On a microscopic basis, the mean square gradient, $\overline{G_x^2}$, gives an indication of curve shape, and is calculated by first dividing the curve into small equal increments, Δx, from the beginning of the curve at x_a to the end of the curve at x_b, and then measuring the corresponding density increment, ΔD, for each division and squaring these values. Finally, the average is found by dividing the sum of these squares by the number of samples, N, i.e.:

$$\overline{G_x^2} = \frac{1}{N} \sum_{i=1}^{n} \left(\frac{\Delta D_i}{\Delta x_i} \right)^2$$

Secondly, on a microscopic basis, the sensation of acutance is also affected by the dynamic density range of the edge, D_r, which is simply the difference between maximum and minimum density, i.e.:

$$D_r = D_{max} - D_{min}$$

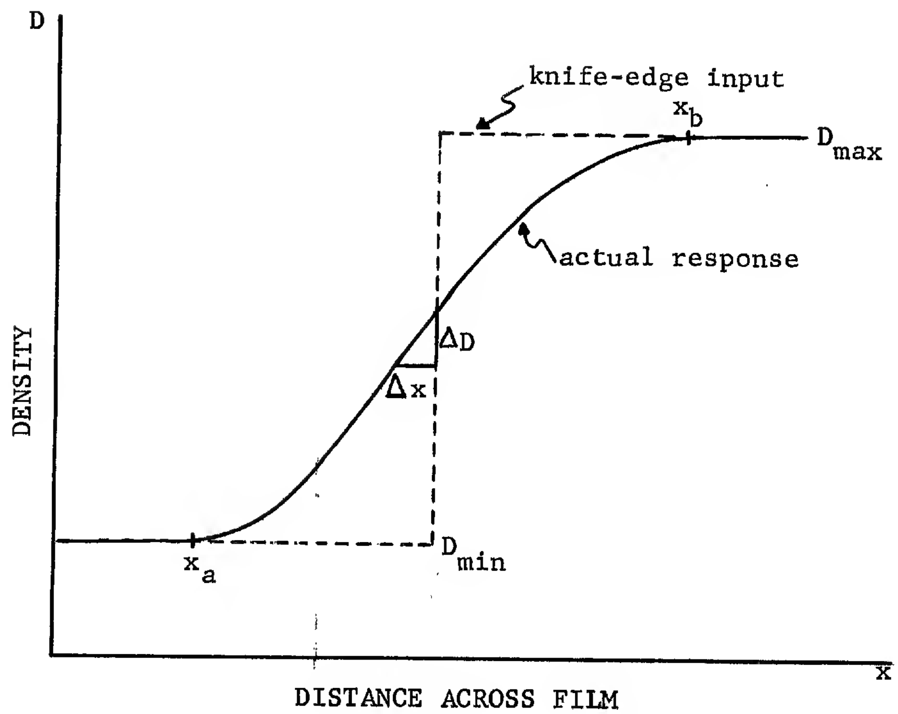

Figure 8

Typical Microdensitometer Trace of a Knife-Edge on Photographic Film Showing the Degradation from a Perfectly Sharp Pulse

The higher the mean square gradient, the more abrupt is the density transition at the edge; conversely, for a given value of $\overline{G_x^2}$, the edge appears sharper as the density scale becomes smaller. The acutance factor is therefore given by

$$A = \frac{\overline{G_x^2}}{D_r}$$

It is apparent that as acutance increases, the decision concerning the exact position of an edge becomes easier to make. The eye, which in conventional mensuration devices is usually aided by optical magnification, effectively broadens the edge and reduces the acutance. The magnifier in a sense acts as a low-frequency pass filter, and as such reduces both contrast and acutance. However, by amplifying the low frequencies, it aids the eye in seeing the edge.

The basic problem one is faced with in deciding where the edge lies is one of relating the density gradient to the original optical image. Since any stage in the reproduction process lowers the sharpness of that edge (with the exception of specialized spatial filtering techniques), it follows that the ability of the observer to make the decision about the position of the edge will be best with the original negative.

An extensive series of experiments would be required to establish numerical data concerning the accuracy of edge measurement as it relates to the resolving power of the system components. However, the factors which will affect that accuracy can be listed:

1. Imaging ability of camera system (frequency response)
2. Imaging ability of original negative film (frequency response)
3. Duplicating printer capability (frequency response)
4. Duplicating film capability (frequency response)
5. Number of generations between original negative and duplicate to be measured
6. Contrast of original detail in aerial image
7. Negative film gamma
8. Developer type, and type of agitation
9. Printing film gamma and exposure level
10. Size of detail to be measured
11. Accuracy of measuring equipment